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Carpino, II et al.

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(54) **PATTERNED ELECTRICAL FOIL HEATER ELEMENT HAVING REGIONS WITH DIFFERENT RIBBON WIDTHS**

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Related U.S. Application Data

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(51) **Int. Cl.**
H05B 3/54 (2006.01)

(52) **U.S. Cl.** **219/528**; 219/385; 219/532; 219/548; 219/553

(58) **Field of Classification Search** 219/528, 219/532, 385, 548, 553; 29/611
See application file for complete search history.

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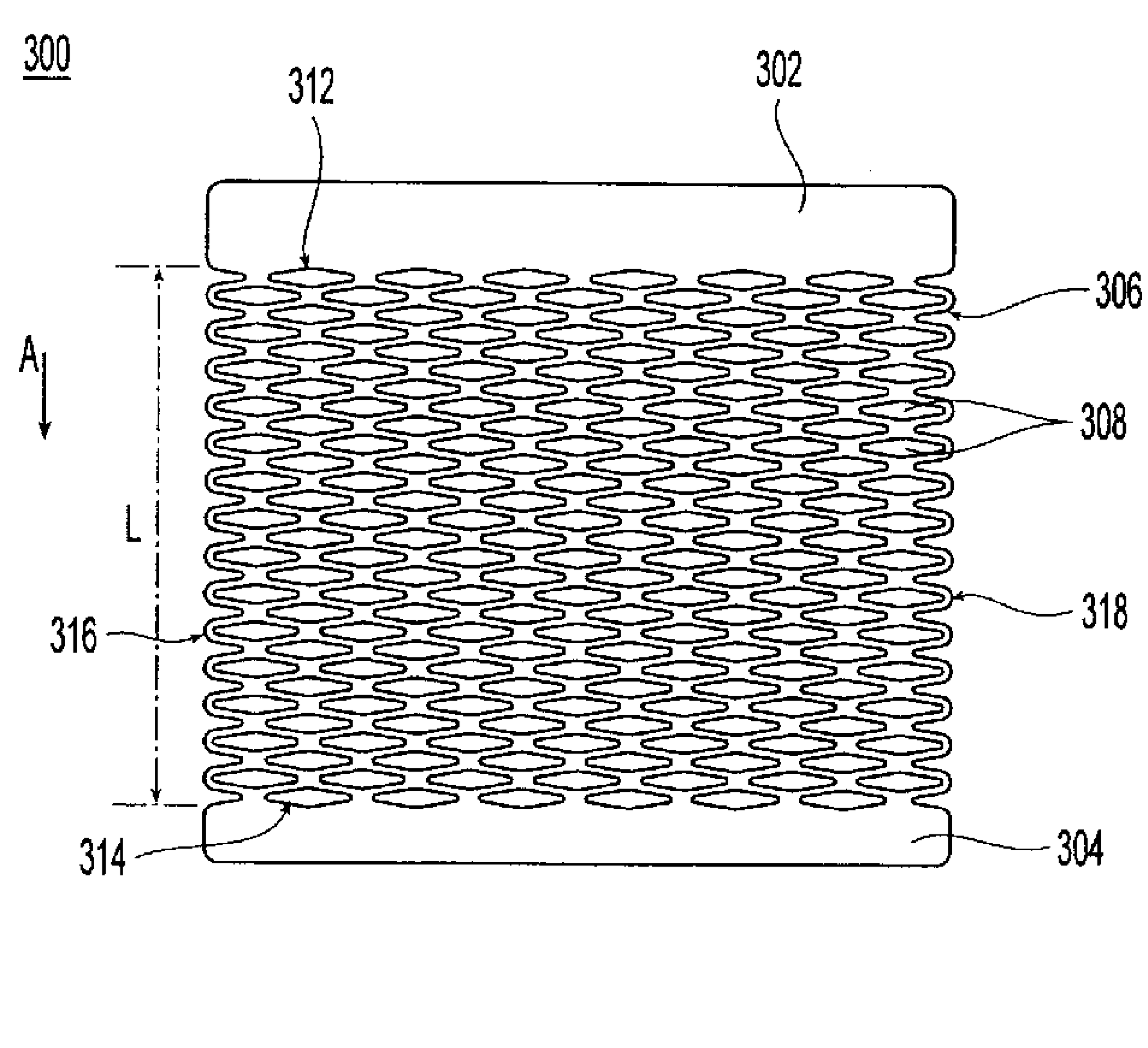
(57) **ABSTRACT**

A patterned foil sheet heating element has a first discrete region patterned with a first plurality of holes forming multiple conductive ribbons and having a first sheet resistivity. It also has a second discrete region patterned with a second plurality of holes forming multiple conductive ribbons and having a second sheet resistivity. At least some of the multiple conductive ribbons in the first discrete region are in electrical continuity with at least some of the multiple conductive ribbons in the second discrete region, and the first discrete region and the second discrete region both adjoin a first junction strip of the foil heating element. An electrothermal heating assembly may be formed using such a patterned foil sheet sandwiched between two layers of material which may be thermally conductive and electrical insulative.

20 Claims, 7 Drawing Sheets



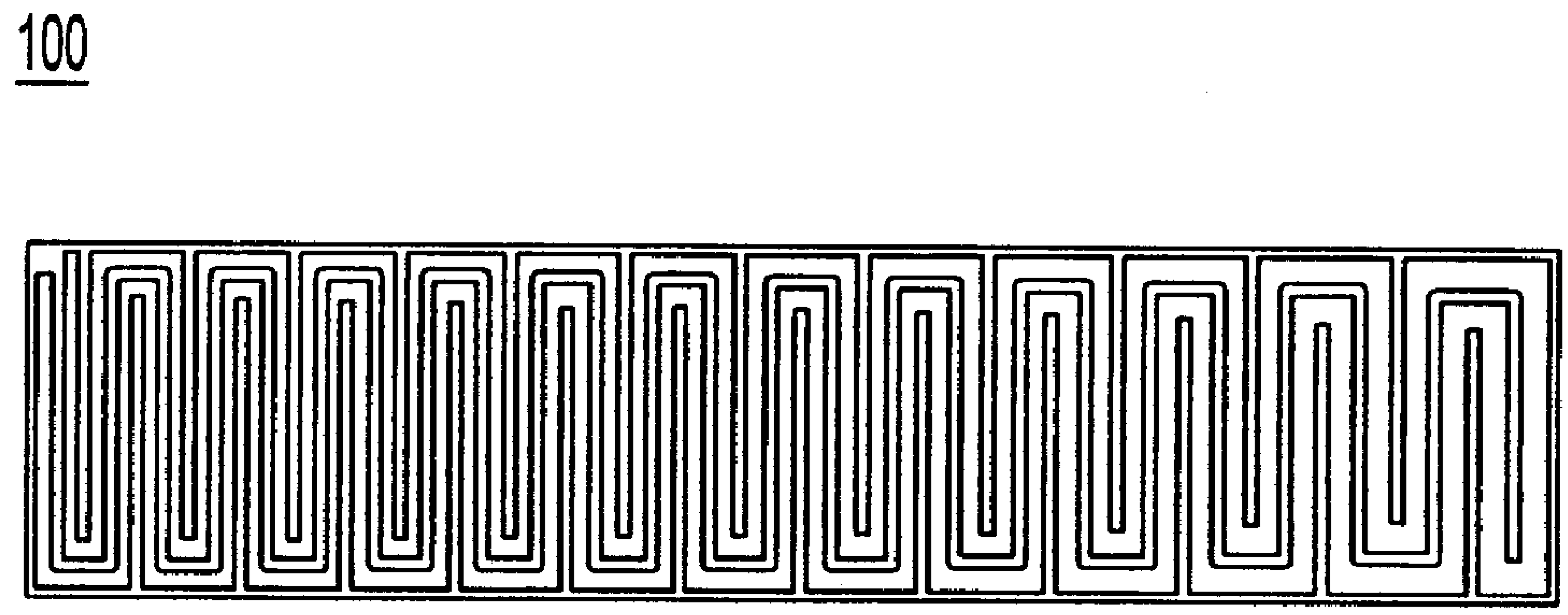


Fig. 1
(Prior Art)

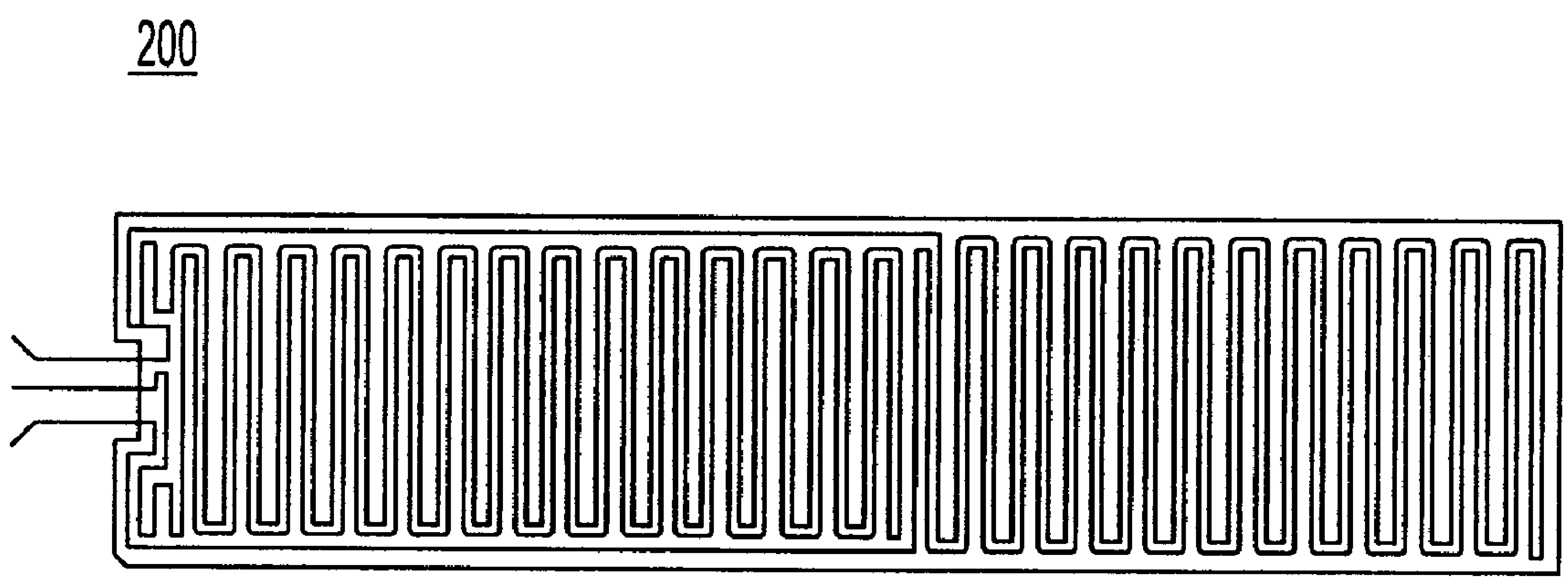


Fig. 2
(Prior Art)

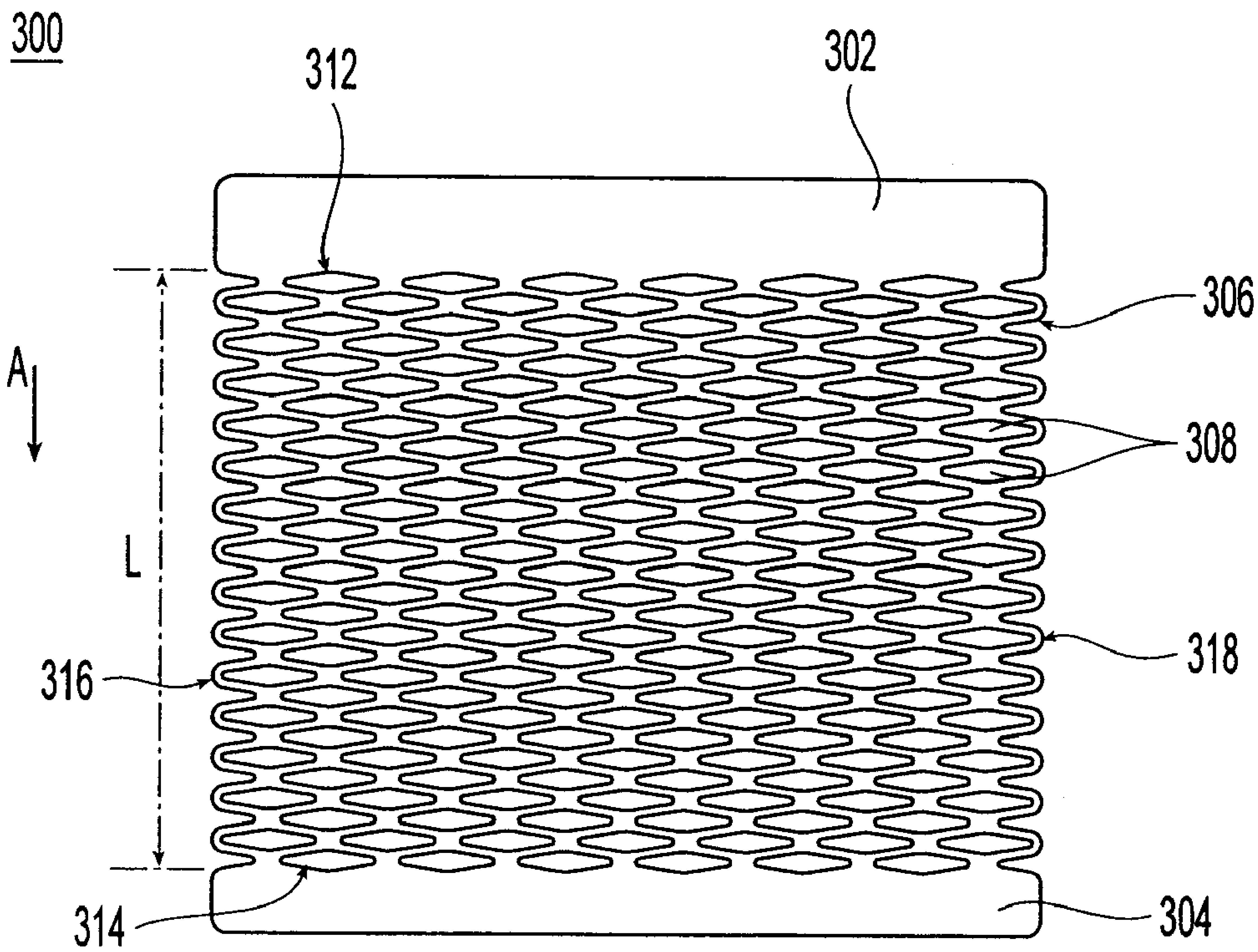

300
312
302
306
A
308
L
318
316
314
304

Fig. 3a

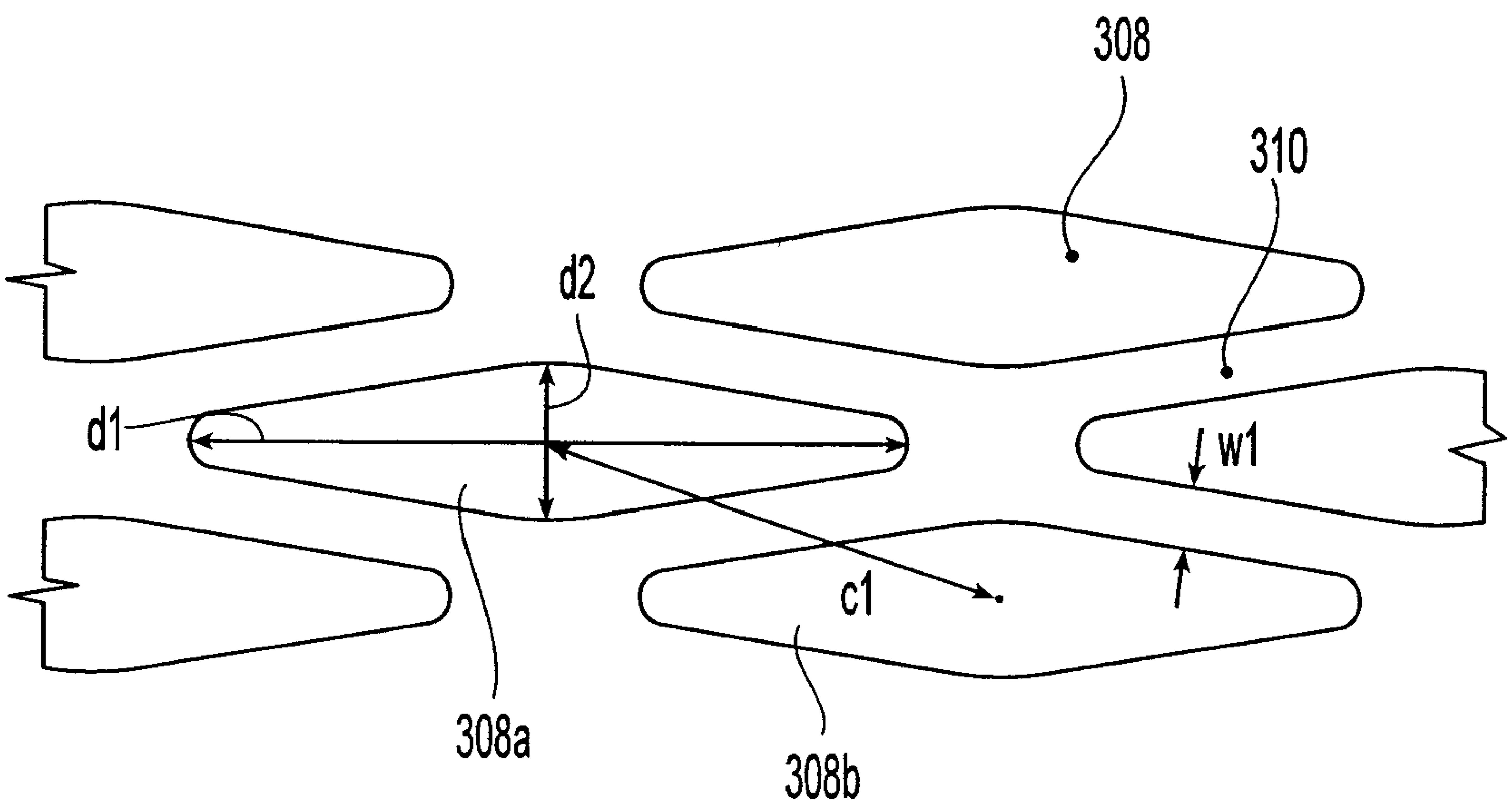

308
310
d2
d1
w1
c1
308a
308b

Fig. 3b

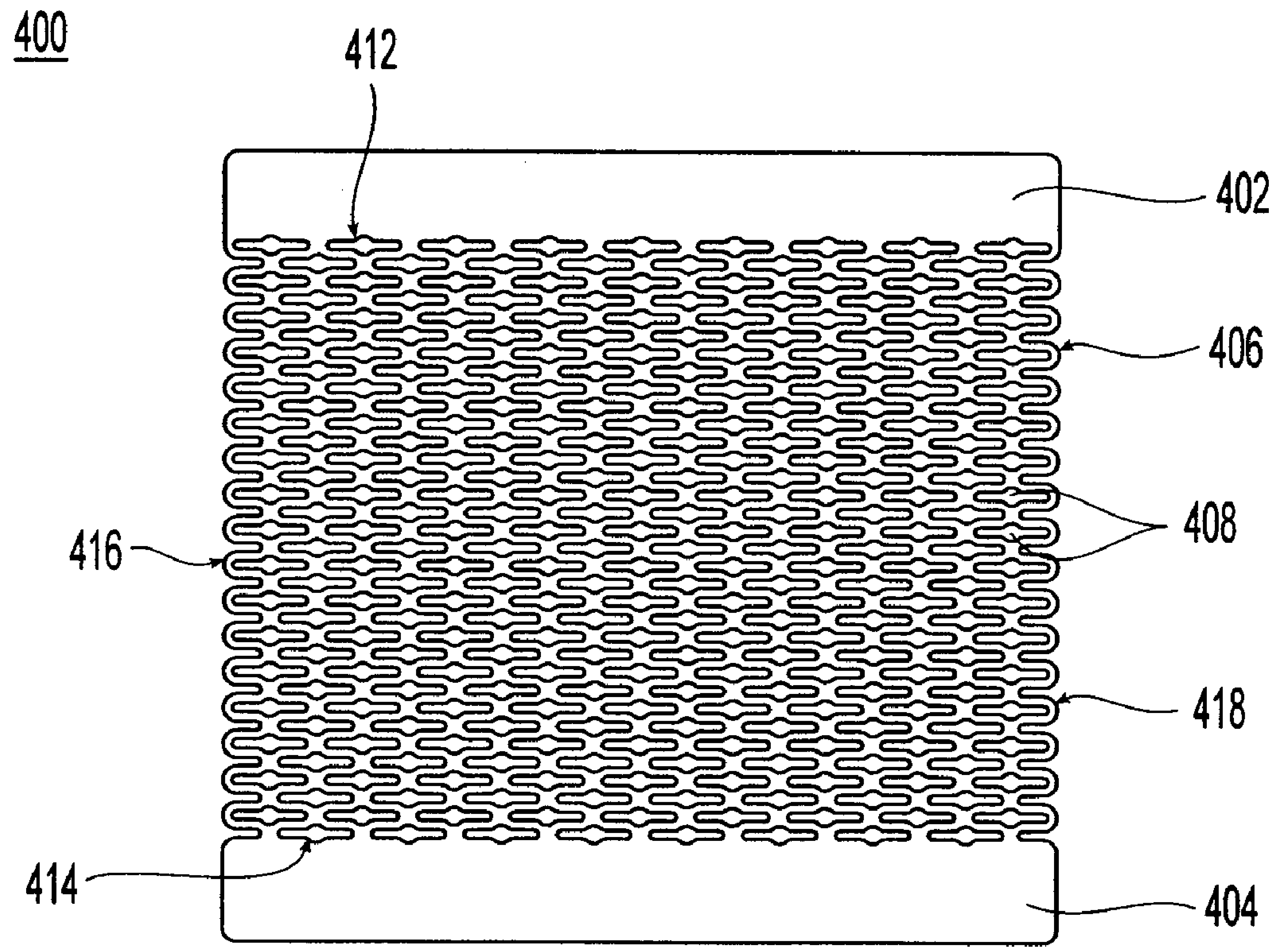


Fig. 4

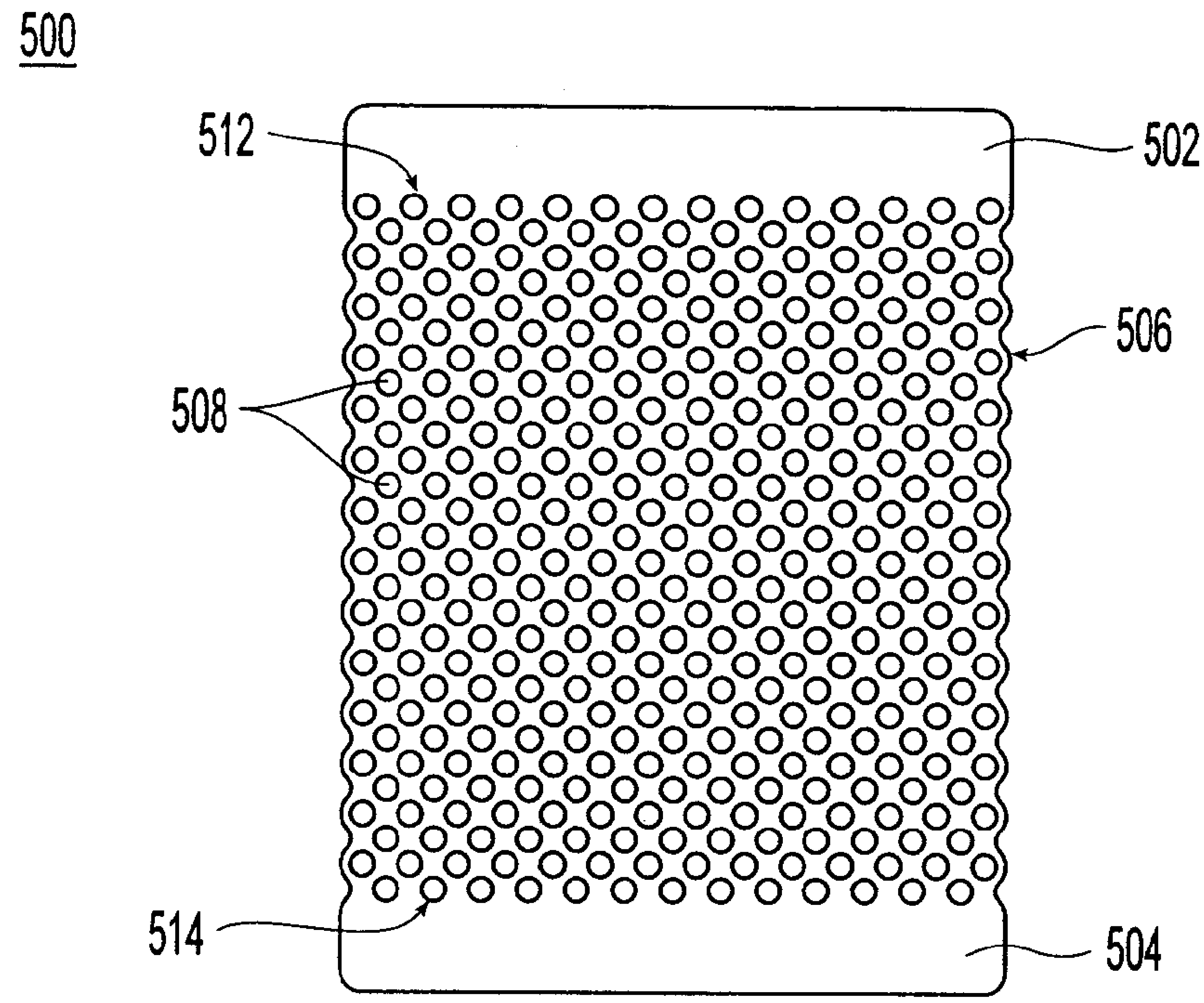


Fig. 5

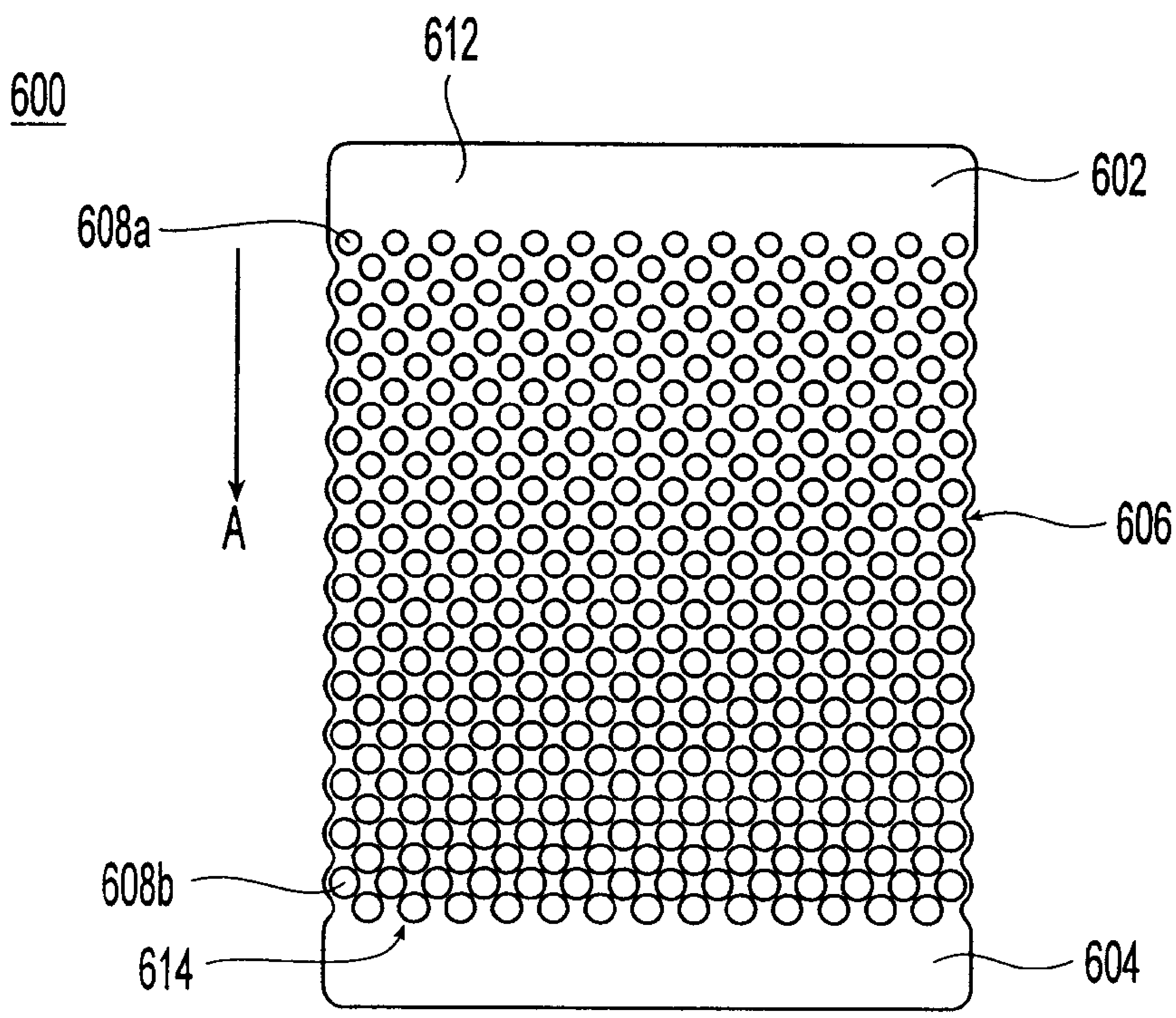


Fig. 6

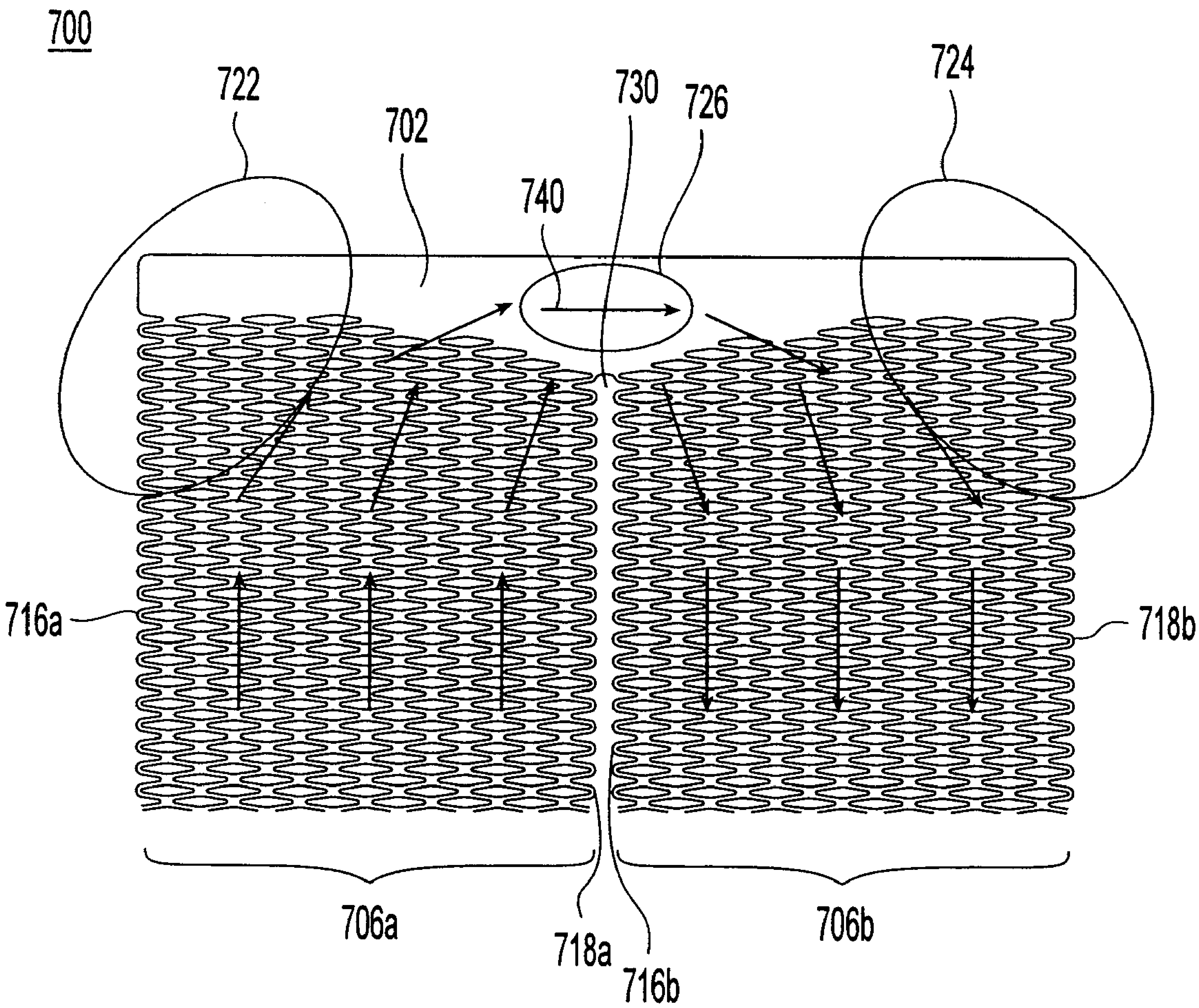


Fig. 7

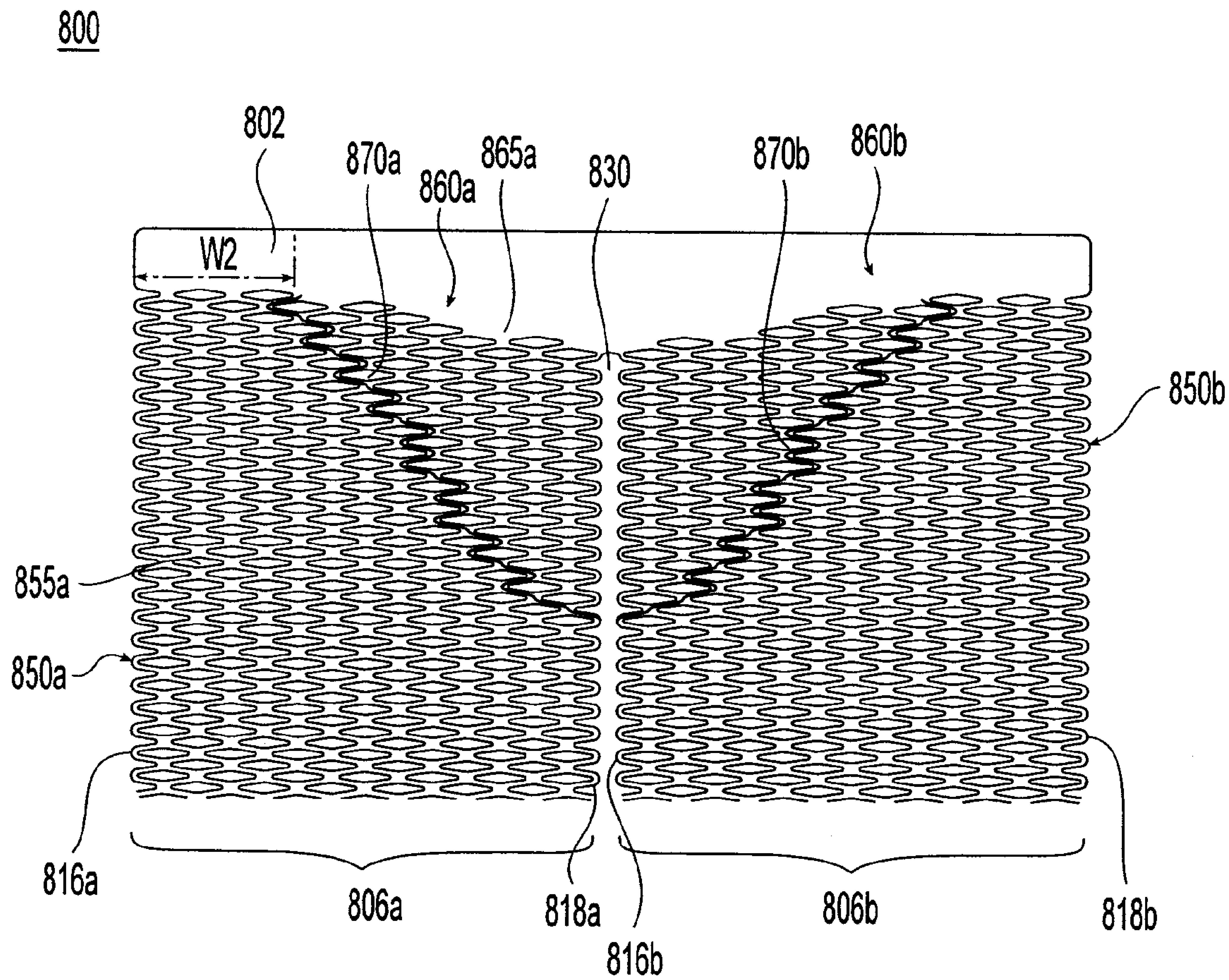
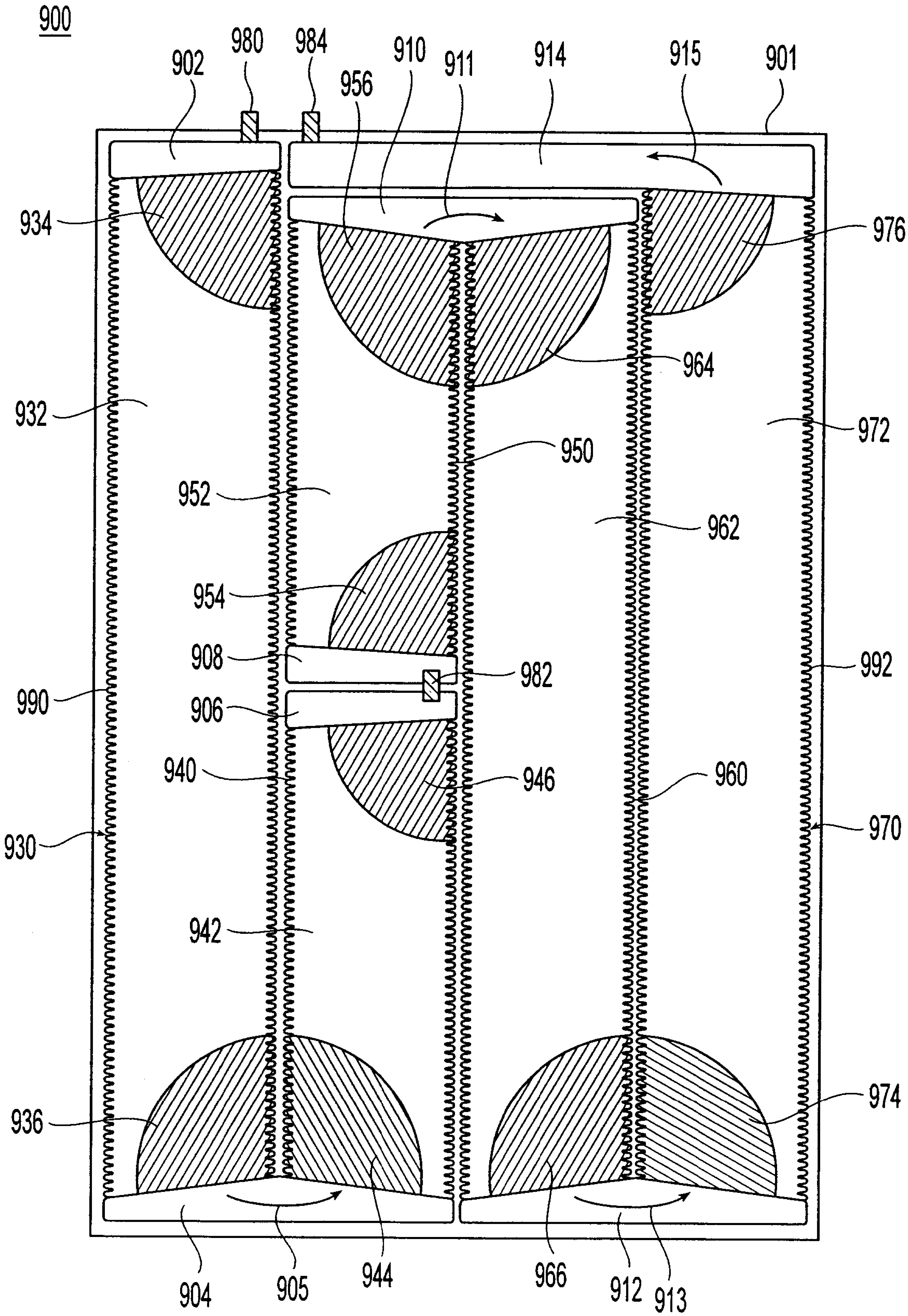

800
802
W2
870a
860a
865a
830
870b
860b
850b
855a
850a
816a
806a
818a
816b
806b
818b

Fig. 8


900
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901
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932
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962
954
908
982
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990
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940
946
960
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970
942
936
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904
905
944
966
912
913

Fig. 9

PATTERNED ELECTRICAL FOIL HEATER ELEMENT HAVING REGIONS WITH DIFFERENT RIBBON WIDTHS

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a Continuation-in-part of U.S. patent application Ser. No. 11/078,707, filed Mar. 14, 2005, whose contents are incorporated by reference in their entirety.

BACKGROUND OF THE INVENTION

Heaters are used in many applications where heat is required to help warm an adjacent area. Electrothermal heating is a common way to warm surfaces and spaces on an aircraft by providing heaters bonded to or integrated within the structure. It may also be used in internal areas of an aircraft, examples in areas such as the cockpit cabin or floors for warming, pipes that may contain liquids that could freeze, and even for volumetric heating of a passenger or air cargo compartment. In electrothermal heating systems, heat energy is typically applied through a metallic heating element via electrical power supplied by aircraft or appropriate application generators. Typical heating elements are made from foil, wire and metallic-coated fabrics.

Generally, the heating element of an electrothermal heater should be highly flexible to conform to many types of surface areas and shapes to be protected. Such surface areas may be either two- or three-dimensional. In addition, such heating elements should also withstand fatigue and foreign object damage (FOD) requirements for each particular application. Further, such heating elements should be capable of being specifically designed to provide exact power levels (heat) and uniform heat distribution to the warmed surfaces or regions.

Most current heater elements are made from a single channel foil or wire element assembly **100**, **200**, respectively, as exemplified by the illustrations of FIGS. **1** and **2**, respectively. Accordingly, a failure or break of the single element via FOD/fatigue in most current heater elements can reduce or eliminate the heating element's usefulness. The prior art also includes a movable sheet having a rectangular array of perforations and mounted on rollers, as disclosed in U.S. Pat. No. 5,590,854; a grid-type of electrical heating element that is painted on, as disclosed in U.S. Pat. No. 6,027,075, and a mesh of interwoven wire, as disclosed in U.S. Pat. No. 6,832,742.

SUMMARY OF THE INVENTION

In one aspect, the present invention is directed to a foil heating element. The foil heating element in accordance with the present invention comprises a patterned foil sheet. The patterned foil sheet includes a first discrete region patterned with a first plurality of holes forming multiple conductive ribbons and having a first sheet resistivity, and it also includes a second discrete region patterned with a second plurality of holes forming multiple conductive ribbons and having a second sheet resistivity. At least some of the multiple conductive ribbons in the first discrete region are in electrical continuity with at least some of the multiple conductive ribbons in the second discrete region, and the first discrete region and the second discrete region both adjoin a first junction strip of the foil heating element.

The differences in sheet resistivity may be the result of using different hole sizes, different hole shapes and varying

the hole center spacings in each region, or combinations of these, in the patterned foil sheet.

In another aspect, the present invention is directed to an electrothermal heating assembly comprising such a foil heating element sandwiched between first and second layers of material. The electrothermal heating assembly may comprises two or more such heating elements, and these may lie in the same plane. Also, the first and second layers of material may be both thermally conductive and electrically insulative.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a first type of prior art electrothermal heating element.

FIG. **2** shows a second type of prior art electrothermal heating element.

FIG. **3***a* shows a foil heating element having a pattern of diamond-shaped holes to form multiple electrical paths.

FIG. **3***b* shows a close-up of the holes seen in FIG. **3***a*.

FIG. **4** shows a foil heating element having a pattern of keyhole-shaped holes to form multiple electrical paths.

FIG. **5** shows a foil heating element having a pattern of circular holes to form multiple electrical paths.

FIG. **6** shows a foil heating element having a pattern of circular holes of varying sizes resulting in varying-width ribbons.

FIG. **7** shows a foil heating element comprising a pair of electrical buses and depicts the current flow between the buses.

FIG. **8** shows a foil heating element comprising a pair of electrical buses in accordance with the present invention.

FIG. **9** shows an electrothermal heating assembly that incorporates a foil heating element of the sort seen in FIG. **8**.

DETAILED DESCRIPTION OF THE INVENTION

FIG. **3***a* shows a patterned foil sheet electrical resistance heating element **300** formed from a single sheet of conductive material. Preferably, it is formed from a sheet of an alloy such as CUPRON® or INCONEL®, materials that are familiar to those skilled in the art. Other materials may also be suitable for this purpose. Such materials come in different thicknesses, but a sheet having an initial thickness of about 5 mil may be preferred for this purpose.

The foil sheet is patterned with a plurality of holes. The patterning can be realized in a number of ways, such as perforating, stamping, etching or by employing other techniques to form holes in such a foil sheet.

In one embodiment etching is employed to form the pattern of holes. Typically, the sheet is initially etched using a patterned mask to form a pattern of openings and then a surface etch of the entire surface is performed to uniformly reduce the sheet thickness. During this surface etch, the sheet's resistance is monitored until a desired value is reached. The resulting sheet is then placed in a laminate comprising electrically insulative, but thermally conductive layers. In one embodiment the etched sheets are sandwiched between a layers of KAPTON® polyimide film, preferably between 1–5 mils thick. In another embodiment the layers may be formed of fiberglass. In still other embodiments, epoxy or neoprene/urethane layers may be used. Other techniques and parameters for manufacturing and laminating such a heating element are known to those skilled in the art.

The heating element **300** seen in FIG. **3***a* comprises a first junction strip **302**, a second junction strip **304**, and a patterned region **306** in-between. The first and second junction strips **302**, **304** may serve as bus connections suitable for electrically connecting to a power supply and/or additional heating elements.

The patterned region **306** comprises a plurality of holes **308** separated by ribbons **310**. As best seen in FIG. **3***b*, the ribbons have a ribbon width w**1** in areas between the holes **308**. The patterned region **306** thus comprises multiple conductive paths, which improve reliability by ensuring that a single break, or even multiple breaks, in the ribbons will not render the heating element **300** useless.

The patterned region **306** has a length L defined by opposite first and second ends **312**, **314**, respectively. A first direction, indicated by the arrow A, is defined from the first end **312** to the second end **314**. The arrow A depicts the overall direction of current flow in the heating element **300**. As seen in FIG. **3**, the boundaries defining the ends **312**, **314** are perpendicular to the overall direction of current flow A. The patterned region **306** is also bounded by lateral edges **316**, **318**. As seen in FIG. **3***a*, the lateral edges **316**, **318** are scalloped, as determined by the shape of the holes **308** immediately adjacent these edges.

In the embodiment of FIG. **3***a*, the first **302** and second **304** junction strips are on opposite ends of the patterned region **306**. The first junction strip **302** forms a first contact region that adjoins the first end **310** portion of patterned region **306**. The first junction strip **302**, which preferably is not patterned, provides the foil sheet **300** with an area to which a first electrical connection may be made. The second junction strip **304** forms a second contact region adjacent the second end portion **312** of patterned region **306**. Like the first junction strip, the second junction strip **304** also is not patterned and provides an area to which a second electrical connection is made.

The holes **308** in the first patterned region **104** results in the creation of multiple electrical paths between the first end **312** and the second end **314**. Furthermore, the holes **308** are arranged in a direction transverse to the first direction A such that the first patterned region **306** is devoid of a continuous section of foil material between the first end **312** and the second end **314** along a line parallel to said first direction A. In other words, when viewed along the first direction A, there is no straight-line path of foil material in areas away from the lateral edges **316**, **318**. This is because the holes **308** are configured and dimensioned such that the multiple electrical paths in areas away from lateral edges of said first patterned region are all non-parallel to said first direction—the paths being forced to travel around the holes.

In the embodiment of FIG. **3***a*, the holes **308** are diamond-shaped and all holes have the same size. In addition, these holes **308** have rounded corners, which help minimize damage due to fatigue. The holes **308** imbue the foil sheet **300** with the above-described characteristics of multiple electrical paths, overlap, and line-of sight properties, among others.

As seen in FIG. **3***b*, the diamond-shaped holes **308** have a major axis d**1** that is perpendicular to direction A and a minor axis d**2** that is parallel to direction A. In addition, diagonally adjacent holes **308**A, **308**B have a constant center spacing c**1** in a first direction. In one embodiment, the diamond-shaped holes **308** of FIG. **3***a* have major axis d**1** of about 1.2 cm and a minor axis d**2** of about 0.23 cm. Since the center spacing c**1** of diagonally adjacent holes are approximately 0.48 cm, the resulting ribbon width w**1** is approximately 0.10 cm. It is understood, however, that these dimensions may vary, depending on the required power and 2-D area of the foil sheet **300**.

Turning to FIG. **4**, the foil sheet **400** has a first junction strip **402**, a second junction strip **404** and a patterned region **406** in-between. The patterned region **406** is bounded by a first end **412**, a second end **414**, a first lateral edge **416** and a second lateral edge **418**. The holes **408** in the patterned region **406** are keyhole-shaped with rounded edges at the ends of the keyhole. A long dimension of the keyhole-shaped holes is oriented transverse to the first direction A representing the overall direction of current flow. The holes **408** imbue the foil sheet **400** with the characteristics discussed above with respect to FIG. **3***a* regarding the creation of multiple electrical paths, overlap, line-of sight properties, etc., in the direction A. Thus, the primary difference between the embodiments of FIG. **3***a* and FIG. **4** is the shape of the holes.

In FIG. **5**, the holes **508** are circular in shape and extend between the junction strips **502**, **504** formed at opposite ends **512**, **514** of the patterned region **506**.

In FIG. **6**, the holes **608** again are circular in shape, and extend between the junction strips **602**, **604** formed at opposite ends **612**, **614** of the patterned region **606**. However, in this embodiment, the holes **608** increase in size between the first end **612** and the second end **614** of the pattern region **606**. The holes **608**A near the first end **612** are seen to be smaller than holes **608**B near the second end **614**. In particular, the holes are monotonically increasing in size from the first end **612** to the second end **614**.

In general, it is understood that varying hole sizes, hole shapes and hole center spacings all influence the sheet resistivity by affecting the ribbon widths (and thus the ribbon cross-sectional area), the path lengths of each ribbon element, and the number of such paths, respectively. Such actions can change the metal volume of a given cross section of the heating element, thereby changing sheet resistivity.

The metal/hole patterns of the heating element embodiments described thus far generate a robustness through their redundant circuitry. They have more ribbons (metal channels) than a typical current heaters seen in FIGS. **1** and **2**, respectively, which have a single metal channel (foil/wire) that is interconnected in both the x and y direction. In the heating element embodiments described above, a breakage of several arteries by FOD or fatigue, for example, will result in only a minimal degradation to heating element functionality. Furthermore, the metal/hole foil pattern in these embodiments may also be tailored to specific heat densities in local areas by chemically etching the metal ribbon surfaces (element thickness) or edges and/or by changing the size, shape and locations of the holes.

FIG. **7** shows a heating element **700** formed from a single sheet of conductive material. The heating element **700** comprises a junction strip **702** that connects a first bus **706**A to a second bus **706**B, the buses being separated along most of their length by a longitudinally extending gap **730**. The first bus **706**A includes first and second lateral edges **716**A, **718**A, respectively while the second bus **706**B includes first and second lateral edges **716**B, **718**B. As seen in FIG. **7**, lateral edge **718**A is across the gap **730** from lateral edge **716**B.

In one embodiment, the junction strip is approximately 12.5 cm wide and has a maximum height of about 1.8 cm at is center, above the gap **730**. The buses **706**A, **706**B are about 6.0 cm wide and the gap **730** has a width of about 0.5

cm. It is understood that these values are only exemplary and that other values for these parameters may be equally suitable.

The lower portions of the buses **706**A, **706**B are not shown in FIG. **7**. However, the buses **706**A, **706**B of the heating element **700** are connected and operated such that current flows through the left bus **706**A towards the junction strip **702**, across at least a portion of the junction strip in the region above the gap **730**, and then flows away from the junction strip **702** through the right bus **706**B. This flow of current is depicted by the arrows **740**.

The left bus **706**A and the right bus **706**B each comprise regions with diamond-shaped holes of the sort seen in the embodiment of FIG. **3***a*. In one embodiment, the holes are all the same size in both buses **706**A, **706**B and so these buses have a uniform pattern of holes.

Ideally, during use, the heating element **700** has a certain output power or heating performance requirement. As a consequence, the heating element **700** generally must maintain a uniform target surface temperature within some tolerance. In the general case, this can be given by X±Y, where X is the target surface temperature and Y is a tolerance, both values being given in degrees. As an example, the target surface temperature may be 130° F.±5° F. When the heating element does not meet the target temperature, cold spots may form in first regions **722**, **724** while hot spots may form in second regions **726** between the first regions. In the exemplary embodiment of FIG. **7**, due to the specific pattern of holes and ribbons, the cold spots are shown to form proximate the corners of the junction strip **702** while hot spots are shown form in regions where the bulk of the current flows through the junction strip **702**.

FIG. **8** shows an embodiment of a heating element **800** in accordance with the present invention. The heating element **800** comprises a junction strip **802** that connects a first bus **806**A to a second bus **806**B, the buses being separated along most of their length by a longitudinally extending gap **830**. The first bus **806**A includes first and second lateral edges **816**A, **818**A, respectively, while the second bus **806**B includes first and second lateral edges **816**B, **818**B, respectively. As seen in FIG. **8**, lateral edge **818**A is across the gap **830** from lateral edge **816**B.

Importantly, in heating element **800**, the first bus **806**A comprises two patterned regions marked **850**A, **860**A. In the embodiment of FIG. **8**, the two patterned regions are separated by a boundary **870**A. In terms of electrical qualities, the first patterned region **850**A has a first sheet resistance and the second patterned region **860**A has a second sheet resistance. More particularly, the second patterned region **860**A has a higher sheet resistance than the first patterned region **850**A. Because of this increased sheet resistance in the second patterned region **860**A, the current is forced to take another path, thus mitigating hot spots that otherwise might be present.

This difference in sheet resistances is the result of each patterned region **850**A, **860**A having a different ribbon-to-gap ratio, which is a ratio of the area of the ribbons that remain to the surface area of the holes formed. In particular, the ribbon-to-gap ratio in the first region **850**A is larger than the ribbon-to-gap ratio in the second patterned region **860**A. This difference in ribbon-to-gap ratios can be correlated to differences in average ribbon widths between the holes in the two patterned regions. It should be evident to one skilled in the art that a smaller average ribbon width translates into a smaller ribbon cross-sectional area, and thus, larger sheet resistance.

By way of example, in the embodiment of FIG. **8**, the ribbon-to-gap ratio in the first patterned region **850**A is 0.62 and the ribbon-to-gap ratio in the second patterned region **860**A is 0.41. Thus, in the embodiment shown, the ribbon-to-gap ratio of the first patterned region **850**A is a factor on the order of 1.5 times as great as the ribbon-to-gap ratio of the second patterned region **860**A. Generally speaking, however, this factor (i.e., the ratio of the larger ribbon-to-gap ratio to the smaller ribbon-to-gap ratio) can range from 1.2 to 2.5, depending on the application. It is further understood that the ribbon-to-gap ratios may be tailored to the material used, the shape and size of the junction strip **802**, and the shape and size of the bus **806**A, among other factors.

In the embodiment exemplified by heating element **800**, the centers of all the holes **855**A, **865**A, regardless of the region **850**A, **860**A to which they belong, are evenly spaced apart. The difference in ribbon-to-gap ratios results from forming holes **855**A of one size in the first region **850**A and holes **865**A of a second, larger size in the second region **860**A. It is understood that differences in sheet resistance in each region can be achieved by one or more of using different hole sizes, different hole shapes and varying the hole center spacings in each region **850**A, **860**A, and combinations thereof.

In the embodiment of FIG. **8**, the second region **860**A comprises a wedge-shaped area bounded on a first side by the first lateral edge **881**A, on a second side by the junction strip **802** and on a third by the boundary **870**A with the first region **850**A. The boundary **870**A is shown in this embodiment to approximately be a 45° diagonal extending from the junction strip **802** to the first lateral edge **881**A. As seen in this embodiment, the boundary **870**A is staggered and follows the contours of laterally outwardly facing portions of larger holes **865**A that are on the border of the two regions **850**A, **860**A. It is understood that in some wedge-shaped embodiments, the boundary may be at an angle other than 45°, and in still other embodiments, the second region **860**A may take on a shape other than a wedge.

Also, in the embodiment of FIG. **8**, the second patterned region **860**A does not extend all the way to the first lateral edge **816**A. Instead, a predetermined width W**2** of the first patterned area **850**A extends along the junction strip **802**. Thus, the junction strip **802** adjoins a section of first patterned region **850**A that extends to the first lateral edge **816**A and also adjoins a section of second patterned area **860**A that extends to the second lateral edge **818**A. Similarly, the gap **830** borders a section of second patterned region **860**A that is proximate the junction strip **802** and also borders a section of the first patterned region **850**A that is away from the junction strip **802**.

The second bus **806**B is similar in construction to the first bus **806**A, having first lateral edge **816**B and second lateral edge **818**B. Second bus **806**B also comprises first patterned region **850**B separated from second patterned region **860**B by boundary **870**B. In the embodiment of FIG. **8**, similar to the first bus **806**A, the boundary **870**B again results in the wedge-shape second patterned region **860**B in the second bus **806**B.

The heating element **800** is made by etching a foil sheet of the type described above using a specially designed mask having at least two different regions, each with different hole sizes. People skilled in the art know how to make such masks, once the pattern is understood.

FIG. **9** shows an electrothermal assembly **900** comprising a plurality of heating elements **990**, **992**, each heating element comprising one or more junction strips and buses.

As shown here, the heating elements **990**, **992** are mounted on a thermal conductive, electrically insulative substrate **901**. In one embodiment of an assembly, the heating elements **990**, **992** are in the same plane and are sandwiched between two layers of such substrate material, as discussed above.

Heating element **990** comprises first junction strip **902**, second junction strip **904**, third junction strip **906**, first bus **930** and second bus **940**. A first electrical contact **980** in communication with the first junction strip **902** provides a first terminal for connecting to a power supply.

The first bus **930** comprises a first patterned region **932** which adjoins both the first junction strip **902** and the second junction strip **904**. The first bus **930** also comprises a second patterned region **934** that adjoins the first junction strip **902** and a third patterned region **936** that adjoins the second junction strip **904**. As seen in FIG. **9**, the wedge-shaped second and third patterned regions **934**, **936** are both bordered by the first patterned region **932**, the junction strips **902**, **904**, respectively, and by a common gap separating bus **930** from buses **940** and **950**.

The sheet resistivities of the second and third patterned regions **934**, **936** both differ from that of the first patterned region **932**. However, the sheet resistivities of the second and third patterned regions **934**, **936** do not have to be the same—they may differ from each other. It is understood that the difference in sheet resistivities between one patterned region and another is the result of differences in hole sizes, hole shapes and/or hole center spacings, all as discussed above. Furthermore, this holds for all the other buses **940**, **950**, **960** and **970**.

The second bus **940** comprises a first patterned region **942** that adjoins both the second junction strip **904** and the third junction strip **906**, a second patterned region **944** that adjoins the second junction strip **904**, and a third patterned region **946** that adjoins the third junction strip **906**.

It is noted here that the second junction strip **904** provides a region where the current turns, as indicated by arrow **905**, from first bus **930** to second bus **940**. The patterned regions **936** and **944**, both of which adjoin the second junction strip **904**, have higher sheet resistivity than the first patterned regions **932**, **942**, respectively, in their respective buses **930**, **940**. This helps reduce the formation of hot spots and cold spots in various portions of the second junction strip **904** and also in portions of the buses **930**, **940** proximate the second junction strip **904**.

The second heating element **992** includes third bus **950**, fourth junction strip **908**, fifth junction strip **910**, fourth bus **960**, sixth junction strip **912**, fifth bus **970** and seventh junction strip **914**.

The third bus **950** comprises a first patterned region **952** that adjoins both the fourth junction strip **908** and the fifth junction strip **910**, a second patterned region **954** that adjoins the fourth junction strip **908**, and a third patterned region **956** that adjoins the fifth junction strip **910**.

The first heating element **990** and the second heating element **992** are electrically connected to one another via a thermal fuse **982**, which typically is a fusible conductor bridging third junction strip **906** and fourth junction strip **908**. The patterned regions **946** and **954** on either side of the thermal fuse **982** help ensure more uniform current flow in the adjacent junction strips **906**, **908** belonging to buses **940**, **950**, respectively.

The fourth bus **960** comprises a first patterned region **962** that adjoins both the fifth junction strip **910** and the sixth junction strip **912**, a second patterned region **964** that adjoins the fifth junction strip **910**, and a third patterned region **966** that adjoins the sixth junction strip **912**.

The fifth junction strip **910** provides a region where the current turns, as indicated by arrow **911**, from third bus **950** to fourth bus **960**. The patterned regions **956** and **964**, both of which adjoin the fifth junction strip **910**, have higher sheet resistivity than the first patterned regions **952**, **962**, respectively, in their respective buses **950**, **960**. This helps reduce the formation of hot spots and cold spots in various portions of the fifth junction strip **910** and also in portions of the buses **950**, **960** that are close to the fifth junction strip **910**.

The fifth bus **970** comprises a first patterned region **972** that adjoins both the sixth junction strip **912** and the seventh junction strip **914**, a second patterned region **974** that adjoins the sixth junction strip **912**, and a third patterned region **976** that adjoins the seventh junction strip **914**.

The sixth junction strip **912** provides a region where the current turns, as indicated by arrow **913**, from fourth bus **960** to fifth bus **970**. The patterned regions **966** and **974**, both of which adjoin the sixth junction strip **912**, have higher sheet resistivity than the first patterned regions **962**, **972**, respectively, in their respective buses **960**, **970**. This helps reduce the formation of hot spots and cold spots in various portions of the sixth junction strip **912** and also in portions of the buses **960**, **970** that are close to the sixth junction strip **912**.

The seventh junction strip **914** provides a region where the current turns, as indicated by arrow **915**, from fifth bus **970** as it travels down an elongated portion of the seventh bus towards second electrical contact **984**. The third patterned region **976** of the fifth bus **970** which adjoins the seventh junction strip **914**, has a higher sheet resistivity than the first patterned region **972** of the fifth bus. This helps reduce the formation of hot spots and cold spots in portions of the seventh junction strip **912** and also in portions of the fifth bus **970** that are close to the seventh junction strip **914**.

The second electrical connector **984** is in communication with the seventh junction strip **914** and provides a second terminal for connecting to a power supply. The seventh junction strip **914** is provided with the elongated portion so that the second electrical contacts **984** is in close physical proximity to the first electrical contact **980**. Thus, the first and second electrical contacts **980**, **984** are sufficiently close to one another that they are connectable to corresponding contacts of a power cable having two or more wires.

As seen in the assembly of FIG. **9**, in a patterned foil heating element, changes in sheet resistivity though varying hole attributes in regions where the current turns, may be used to reduce the likelihood of hot spots and cold spots. This may facilitate attaining temperature uniformity specification of such foil heating elements, and assemblies incorporating the same.

People skilled in the art know how to make and use electric heaters for aircraft de-icing and other applications, as exemplified by U.S. Pat. Nos. 5,475,204, 5,590,854, 6,027,075, 6,237,874 and 6,832,742, all of whose contents are incorporated by reference to the extent necessary to understand the present invention.

The above description of various embodiments of the invention is intended to describe and illustrate various aspects of the invention, and is not intended to limit the invention thereto. Persons of ordinary skill in the art will understand that certain modifications may be made to the described embodiments without departing from the invention. All such modifications are intended to be within the scope of the appended claims.

What is claimed is:

1. A foil heating element comprising:

a patterned foil sheet having:

a first discrete region patterned with a first plurality of holes forming multiple conductive ribbons and having a first sheet resistivity; and

a second discrete region patterned with a second plurality of holes forming multiple conductive ribbons and having a second sheet resistivity, wherein:

at least some of the multiple conductive ribbons in the first discrete region are in electrical continuity with at least some of the multiple conductive ribbons in the second discrete region; and

the first discrete region and the second discrete region both adjoin a first junction strip of the foil heating element.

2. The foil heating element according to claim **1**, wherein:

the holes within the first discrete region are all a first size

the holes within the second discrete region are all a second size; and

the first and second sizes differ from one another.

3. The foil heating element according to claim **2**, wherein:

the holes in the first discrete region have a first center spacing;

the holes in the second discrete region have a second center spacing; and

the first center spacing and the second center spacing are the same.

4. The foil heating element according to claim **2**, wherein:

the holes in the first discrete region have a first shape;

the holes in the second discrete region have a second shape; and

the first shape and the second shape are the same.

5. The foil heating element according to claim **4**, wherein:

the holes in the first discrete region have a first center spacing;

the holes in the second discrete region have a second center spacing; and

the first center spacing and the second center spacing are the same.

6. The foil heating element according to claim **1**, wherein:

the holes in the first discrete region have a first average center spacing;

the holes in the second discrete region have a second average center spacing; and

the first average center spacing and the second average center spacing differ from one another.

7. The foil heating element according to claim **1**, wherein:

the holes in the first discrete region have a first shape;

the holes in the second discrete region have a second shape; and

the first shape and the second shape differ from one another.

8. The foil heating element according to claim **1**, wherein:

the first discrete region has a first ribbon-to-gap ratio;

the second discrete region has a second ribbon-to-gap ratio; and

the first ribbon-to-gap ratio differs from the second ribbon-to-gap ratio.

9. The foil heating element according to claim **8**, wherein:

the holes within the first discrete region are all a first size

the holes within the second discrete region are all a second size; and

the first and second sizes differ from one another.

10. The foil heating element according to claim **9**, wherein:

the holes in the first discrete region have a first center spacing;

the holes in the second discrete region have a second center spacing; and

the first center spacing and the second center spacing are the same.

11. The foil heating element according to claim **9**, wherein:

the holes in the first discrete region have a first shape;

the holes in the second discrete region have a second shape; and

the first shape and the second shape are the same.

12. The foil heating element according to claim **11**, wherein:

the holes in the first discrete region have a first center spacing;

the holes in the second discrete region have a second center spacing; and

the first center spacing and the second center spacing are the same.

13. The foil heating element according to claim **1**, wherein:

the holes within the first discrete region form multiple electrical paths having a first average ribbon width;

the holes within the second discrete region form multiple electrical paths having a second average ribbon width; and

the first average ribbon width and the second average ribbon width differ from one another.

14. The foil heating element according to claim **1**, further comprising:

a third discrete region patterned with a third plurality of holes forming multiple conductive ribbons and having a third sheet resistivity, the third discrete region also adjoining said first junction strip of the foil heating element.

15. An electrothermal heating assembly comprising:

a first foil heating element sandwiched between first and second layers of material, the first foil heating element comprising:

a patterned foil sheet having:

a first discrete region patterned with a first plurality of holes forming multiple conductive ribbons and having a first sheet resistivity; and

a second discrete region patterned with a second plurality of holes forming multiple conductive ribbons and having a second sheet resistivity, wherein:

at least some of the multiple conductive ribbons in the first discrete region are in electrical continuity with at least some of the multiple conductive ribbons in the second discrete region; and

the first discrete region and the second discrete region both adjoin a first junction strip of the foil heating element.

16. The electrothermal heating assembly according to claim **15**, further comprising:

a second foil heating element electrically connected to said first foil heating element, and also sandwiched between said first and second layers of material.

17. The electrothermal heating assembly according to claim **16**, wherein the first and second foil heating elements are in the same plane.

18. The electrothermal heating assembly according to claim **16**, wherein the first and second foil heating elements are connected by a thermal fuse.

19. The electrothermal heating assembly according to claim **16**, wherein:

the first foil heating elements is provided with a first electrical contact;

the second foil heating elements is provided with a second electrical contact; and

the first and second electrical contacts are sufficiently close to one another that they are connectable to corresponding contacts of a power cable.

20. The electrothermal heating assembly according to claim **16**, wherein the first and second layers of material are thermally conductive and electrically insulative.

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